IN THE UNITED STATES DISTRICT COURT
FOR THE NORTHERN DISTRICT OF OKLAHOMA

STATE OF OKLAHOMA, *et al.*,	)	
	)	
Plaintiffs,	)	
	)	
v.	)	**Case No. 4:05-cv-00329-GKF-PJC**
	)	
TYSON FOODS, INC., *et al.*,	)	
	)	
Defendants.	)	
	)	

DECLARATION OF DR. JOHN CONNOLLY, Ph.D.

1. My name is John P. Connolly. I am a partner with Anchor QEA, LLC, an environmental consulting firm.

2. I have been retained by the Defendants in this matter to assess whether the use of poultry litter as a fertilizer in the Illinois River Watershed adversely impacts water quality in the Watershed.

3. I previously authored and submitted to my clients an expert report detailing my work and conclusions in this matter. I understand that this report was served on Plaintiffs. I incorporate that report herein by reference.

4. If called to testify at trial, I would testify consistent with the opinions expressed in that report.

I declare under penalty of perjury that the foregoing is true and correct.

Executed 4 June, 2009

John Connolly

Dr. John Connolly
Anchor QEA, LLC

Expert Report

Illinois River Watershed Water Quality and Source Assessment

Prepared for:

Illinois River Watershed Joint Defense Group

Prepared by:

Quantitative Environmental Analysis, LLC

Montvale, NJ

January 30, 2009

UNITED STATES DISTRICT COURT
FOR THE NORTHERN DISTRICT OF OKLAHOMA

STATE OF OKLAHOMA, ex. rel. W.A. DREW EDMONDSON, in his capacity as ATTORNEY GENERAL OF THE STATE OF OKLAHOMA and OKLAHOMA SECRETARY OF THE ENVIRONMENT, J.D. Strong, in his capacity as the TRUSTEE FOR NATURAL RESOURCSE FOR THE STATE OF OKLAHOMA,	)	
Plaintiffs,	)	
	)	**Case No. 05-CV-329-GKF-SAJ**
v.	)	
TYSON FOODS, INC., TYSON POULTRY, INC., TYSON CHICKEN, INC., COBB-VANTRESS, INC., AVIAGEN, INC., CAL-MAINE FOODS, INC., CAL-MAINE FARMS, INC., CARGILL, INC., CARGILL TURKEY PRODUCTION, LLC, GEORGE'S INC., GEORGE'S FARMS, INC., PETERSON FARMS, INC., SIMMONS FOODS INC., and WILLOW BROOK FOODS, INC.,	)	
Defendants.	)	

EXPERT REPORT OF

John P. Connolly, Ph.D., P.E., B.C.E.E.

QEA
Quantitative Environmental Analysis, LLC
∂c/∂t

January 30, 2009

quality issues that exist in Lake Tenkiller. There are other factors affecting water quality in Lakes Tenkiller, Hugo, and Sardis. These include:

1. urban and rural development which increases impervious cover, lawn and golf course fertilization, wastewater treatment plant (WWTP) discharges, and the number of septic systems in the watershed (Nelson et al. 2002; Soerens 2003; Sonoda 2007);
2. deforestation and related erosion (Perry et al. 1999; Zheng 2005; Grip 2008; Grip 2009);
3. row crop synthetic fertilizers and related erosion (Sharpley and Smith 1990; Sharpley et al. 2003; Wortmann 2005);
4. other livestock operations such as cattle and swine (USDA 2003; Shaffer 2005; Wortmann 2005; Beede 2007); and
5. inputs from humans during recreational use (see Jarman 2008 for discussion).

Finally, and most importantly, altering a natural system via dam construction inevitably results in water quality issues. These water quality issues arise due to restricting sediment flux out of a watershed and decreasing the potential and kinetic energy of the system, which increases residence time in the water body and thus promotes growth of phytoplankton.[8]

2.9 WASTEWATER TREATMENT PLANTS APPEAR TO BE THE MOST IMPORTANT SOURCE OF BIOAVAILABLE PHOSPHORUS TO THE SYSTEM

Many wastewater treatment plants in the Arkansas and Oklahoma portions of the Illinois River Watershed installed significant upgrades within the past decade, the majority of which were in place by 2004 (Jarman 2008). Improvements have been seen in water quality

[8] Lakes Hugo and Sardis watersheds do not have significantly more urbanization, human population, or other animal populations compared to Lake Tenkiller. Consequently, the water quality issues observed in Lakes Hugo and Sardis even with the lower poultry populations can not be attributed to just urbanization, deforestation, or other animal populations.

immediately downstream of these facilities, and in some cases the water quality improvements have been noted far downstream in the wider Illinois River Watershed.

Wastewater treatment plants and their impact on Illinois River waters have been studied for numerous years. Haggard et al. (2003) and Ekka et al. (2003) indicate that base flow concentrations of phosphorus were elevated for streams receiving WWTP discharges. Haggard (2005) attributes decreased dissolved phosphorus concentrations in Spring Creek, and downstream in Osage Creek and the Illinois River, to upgrades to the Springdale municipal WWTP. Arkansas Department of Environmental Quality (ADEQ; 2008a) notes decreases in phosphorus concentrations in Siloam Springs, Sager Creek, and Little Sugar Creek over the past decade, in conjunction with treatment plant upgrades. Arkansas Water Resources Center (AWRC 2007) associated reduced total phosphorus base flow loads downstream of Siloam Springs to reduced wastewater treatment plant effluent loads, and found a strong correlation.

WWTP impacts continue to be seen in the water bodies in the Illinois River Watershed. Twenty-two percent of the impaired water bodies in the Oklahoma portion of the watershed include ‘municipal point sources’ as potential causes of the impairment (ODEQ 2008). 8.1 miles of Sager Creek remain impaired due to municipal point sources (ADEQ 2008b).

There are nine notable WWTPs that discharge to the streams of the Illinois River Watershed. Three are in Oklahoma and six are in Arkansas. Information about these plants is presented in Table 2-13.

Table 2-13. Wastewater treatment plants discharging to the Illinois River Watershed.

Plant	State	Receiving Water	Connection to the Illinois River	Average Total Phosphorus Load 2004 to 2007 (kg/yr)
Prairie Grove	AR	Unnamed tributary of Muddy Fork	Muddy Fork	2,000
Fayetteville – West	AR	Mud Creek (2004 – June 2007) Goose Creek (July 2007 – present)	Clear Creek Goose Creek	2,300
Springdale	AR	Spring Creek	Osage Creek	11,300
Rogers	AR	Osage Creek	Osage Creek	5,700
Siloam Springs	AR	Sager Creek	Flint Creek	13,000
Tahlequah	OK	Tahlequah Creek	Tahlequah Creek	1,200
Lincoln	AR	Unnamed tributary of Bush Creek	Baron Fork	270
Westville	OK	Shell Branch of Baron Fork	Baron Fork	330
Stillwell	OK	Caney Creek	Caney Creek	900

In total, over the period from 2004 to 2007 these plants discharged an average of almost 37,000 kg of phosphorus per year to the streams of the Illinois River Watershed, not counting any spikes in discharge that may have occurred due to plant upsets or short-circuiting during storm events (Jarman 2008). Much of the phosphorus entering the streams from these plants is dissolved and most of the dissolved phosphorus is reactive (i.e., SRP), the form that stimulates plant growth. This fact is evident in Figure 2-23, which shows the fraction dissolved and fraction of dissolved that is SRP for phosphorus measurements conducted by the Plaintiffs on WWTP effluent.

The influence of the WWTPs is evident in the spatial pattern of phosphorus concentrations in the rivers and streams of the Illinois River Watershed, as shown in Figure 2-24a. The highest total phosphorus concentrations (typically red or orange symbols) are found almost always just downstream of WWTPs (yellow diamonds in the figure). Moving further downstream there is typically a downward trend in concentrations indicated by the transition to green, light blue and finally dark blue symbols. High concentrations occur at a few stations remote from WWTPs, but the only organized spatial patterns are tied to the WWTPs.[9] A similar pattern exists for SRP, which is shown in Figure 2-24b.

[9] The location of the wastewater treatment facility in Watts, OK is also indicated on these figures. This is a retention and land application facility and is not permitted to discharge, however at least one release is documented (Jarman 2008). Sampling data from the Illinois River immediately downstream of the Watts facility is not available,

A more quantitative examination of the spatial patterns is presented in Figure 2-25, which shows the upstream to downstream trend in SRP concentrations in the Illinois River for three time periods (1998 to 2000; 2001 to 2003; 2004 to 2008). Red arrows indicate the locations where major tributaries enter the Illinois River. Moving from upstream to downstream, there is a gradual increase in SRP concentration from levels less than 0.01 mg/L to about 0.03 mg/L just above Muddy Fork (data only in the 2004-2008 period). The two sampling locations between Muddy Fork and Osage Creek exhibit similar concentrations in the range of 0.03 to 0.05 mg/L. The first station downstream of Osage Creek has concentrations in the neighborhood of 0.15 mg/L, a substantial increase from the nearest upstream station. This increase suggests that Osage Creek is an important source of SRP to the Illinois River. The reach between Osage Creek and Lake Frances shows increases in the two earlier time periods (though not statistically significant) and a statistically significant[10] decrease in the latest period. Concentrations generally decline between Lake Frances and Lake Tenkiller reaching about 0.07 to 0.09 mg/L just above Lake Tenkiller. The locations where these samples were collected are identified on Figure 2-26.

Given the apparent importance of Osage Creek, the spatial pattern in this creek and its tributaries was examined. Focusing on the 2004-2008 period (Figure 2-27), which has the best spatial coverage, and August 2006 (Figure 2-28) to provide a synoptic view, it is apparent that the influence of Osage Creek on SRP in the Illinois River is due to WWTPs. Beginning on Spring Creek, SRP concentrations are less than 0.1 mg/L upstream of the Springdale WWTP and about 0.45 mg/L just downstream of the plant. On average, levels decline to about 0.2 mg/L just upstream of the confluence with Osage Creek, although they are at 0.35 mg/L in August 2006. In Osage Creek, the concentration is about 0.01 mg/L upstream of the Rogers WWTP and 0.25 mg/L downstream of the plant. There is a drop to about 0.15 mg/L just upstream of the confluence with Spring Creek and an increase to close to 0.2 mg/L downstream of the confluence. Just above the confluence with Illinois River the concentration is about 0.12 mg/L (0.2 mg/L in August 2006). Similar patterns are shown in data measured before 2004

[10] Statistical significance inferred when differences fall outside the 2 standard error range indicated by the error bars around the mean values.

(Figure 2-29), indicating that historically, WWTP discharges had an influence on the phosphorus concentrations in the rivers and streams. See Figure 2-26 for sampling locations.

Wastewater treatment plants impact phosphorus concentrations in the Illinois River every day, whereas most other sources (except perhaps septic tanks) contribute only during runoff events that occur periodically and somewhat infrequently during the summer season when phosphorus impacts water quality. In fact, the amount of phosphorus in the Illinois River under base flow conditions corresponds to the amount that entered upstream from WWTPs, indicating that the WWTPs are the dominant source of phosphorus during base flow. This correspondence is shown in Figure 2-30, which displays the distribution of base flow phosphorus loadings measured by the United States Geological Survey (USGS) in the river at monitoring stations at Watts and Tahlequah and shows as vertical lines the average daily loading from the WWTPs. The average load from the WWTPs matches the central tendency base flow load in the river. The variability in the river around the central tendency likely reflects the day-to-day variability in WWTP load.

The 2004-2006 average daily wastewater treatment plant total phosphorus loads were also compared to 2004-2006 Illinois River and tributary average daily total phosphorus loads under base flow (WWTP data for 2007 were incomplete, therefore 2007 is not shown). Available daily flow and total phosphorus data from USGS gauging stations at Watts, Tahlequah, Baron Fork, and Caney Creek were used to estimate average daily total phosphorus loads with LOADEST, a program that estimates average loads through a rating curve method (Runkel et al. 2004).[11] As shown in Figure 2-31, the wastewater treatment plant loads (per Jarman 2008) are reasonable matches to the base flow loads in 2005 and 2006. The treatment plant loads appear lower than the in-river base flow loads in 2004 when frequent and significant high flow events potentially biased the estimation of base flow (i.e., some high flows identified as base flows may have included surface runoff) and the elevated base flows may have introduced a greater load from septic systems (see Figure C-1 to note the high base flows in

[11] LOADEST estimated daily loads with available paired daily average flow and total phosphorus data. Daily average flow data were used because instantaneous flow data were not available at all locations. Daily average total phosphorus loads are averages of daily total phosphorus loads estimated by LOADEST. LOADEST load estimates were generated using the model's Method 8 and separate rating curves were produced for each year.

2004). Note, the locations labeled as Baron Fork and Caney Creek in Figure 2-31 refer to the points in the Illinois River where the Baron Fork and Caney Creek tributaries meet the Illinois River.

In contrast to base flow phosphorus, runoff–associated phosphorus is not present in the river on a day-to-day basis. In addition, much of the runoff phosphorus load is associated with particulate matter, which would have little direct impact on water quality (it can exert an influence via recycle from sediments). This fact is illustrated in Figure 2-32, which shows the fraction of total phosphorus that is particulate in relation to river flow (particulate phosphorus is calculated by subtracting dissolved phosphorus from total phosphorus). A consistent increase with increasing flow is evident.

The particulate phosphorus associated with runoff events will only settle out of the water column when the river velocity is less than about 15 miles/day (Ziegler et al. 2000). Due to the high velocities characteristic of the Illinois River within Oklahoma[12] (Figure 2-33), little of the particulate phosphorus settles in the river. Much of the runoff particulate phosphorus likely settles out in Lake Tenkiller. This sediment phosphorus might later contribute to phosphorus levels in the lake if it fluxes out of the sediment, but in general it has limited bioavailability (see section 2-10).

During the summer season (May to September), the river experiences runoff conditions only about 20% of the time.[13] Due to the short duration of runoff events, their relative infrequency, and the nature of the phosphorus, run-off associated phosphorus has little impact on water quality, except possibly within Lake Tenkiller.

[12] River velocities determined using Manning's Equation with a Manning's roughness coefficient of 0.04; slope determined from USGS gage heights (when available) or Google map topographic elevations, and river distances determined from GIS using Environmental System Research Institute data; depths of water surface determined from USGS depth data coincident with average summer-time flow rates at each USGS gage location. Riverine portion of lake velocities determined by dividing summer-time average flow rate just downstream of Baron Fork by the approximated cross section of the riverine portion of the lake between Baron Fork and LK04; distance from Baron Fork to LK04 determined from GIS.

[13] The contributions of base flow and runoff flow to the river hydrograph was determined using a base flow separation methodology described in Appendix C.

3.3 BENTHIC ALGAE ARE RARELY AT DENSITIES CONSIDERED A NUISANCE

Dr. Jan Stevenson, a Plaintiffs' consultant, cites two studies in his report indicating that benthic algae become a nuisance at densities greater than 10-15 µg chlorophyll-a/cm^2. Above these threshold densities filamentous species tend to dominate and cover greater than 20% of the stream bottom (Welsh et al. 1988). The USEPA reports that below 15 µg/cm^2 the aesthetic quality use will probably not be appreciably degraded by filamentous mats or other adverse effects attributed to dense mats of filamentous algae (USEPA 2000). Biggs (2000) recommended setting maximum algal biomass of 20 µg/cm^2 with a 30% maximum coverage of visible stream bed by filamentous algae for the protection of aesthetic and trout fishing values for rivers and streams in New Zealand. In a study of over 200 North American and New Zealand streams and rivers, Dodds et al. (1998) suggested the mesotrophic-eutrophic boundary of 20 µg/cm^2. In 2004, Montana Department of Environmental Quality recommended the several numeric criteria for wadeable streams in Montana's Hi-line region, a region covered mainly with semi-arid grasslands used extensively for livestock grazing and growing cereal grain crops. The criteria included maximum streambed cover by filamentous algae of 30% and benthic algae maximum density of 11 µg/cm^2 (Suplee 2004).

The measurements of benthic algae conducted in the Oklahoma portion of the Illinois River and its tributaries by the Plaintiffs' consultants, which are summarized as frequency distributions in Figure 3-2, show that nuisance densities are rare.[19] In summer 2006, the maximum density was 13.8 µg chlorophyll-a/cm^2 and about 95% of the stations had densities less than 10 µg chlorophyll-a/cm^2. In spring 2007, the maximum density was 33.5 µg chlorophyll-a/cm^2, but almost 90% of the stations had densities less than 10 µg chlorophyll-a/cm^2. Densities above 10 µg chlorophyll-a/cm^2 occurred principally in tributaries and frequently downstream of WWTPs. Only one station in the Illinois River in each sampling year had a value greater than 10. Higher values were prevalent in Spring Creek and Sager Creek

[19] The rarity of nuisance benthic algal blooms also invalidates Dr. Stevenson's use of 0.027 mg/L total phosphorus as a benchmark to understand when a particular river or stream in the Illinois River Watershed would have aesthetic issues or "damages". Nuisance levels of benthic algae are rarely measured, yet surface water concentrations of total phosphorus in the Illinois River are routinely above 0.027 mg/L. This fact promotes the establishment of a site-specific benchmark using the available data, as suggested in Stevenson et al. 2006 and Dodds et al. 1997.

as shown in Figure 3-3. On both tributaries, the higher values were found downstream of WWTPs; Siloam Springs on Sager Creek and Springdale on Spring Creek.

The influence of WWTPs on benthic algae is also evident in a USEPA Region 6 2003 study of diel dissolved oxygen variations upstream and downstream of WWTPs (Parsons and UA 2004). Diel dissolved oxygen variations downstream of the Prairie Grove WWTP on Muddy Fork are much greater than exist upstream (Figure 3-4a), indicating a high density of benthic algae. In contrast, little upstream to downstream change is evident around the Rogers WWTP on Puppy Creek (Figure 3-4b). A notable difference between the sites is the slope of the receiving stream; Puppy Creek slopes about 2 feet/mile, whereas Muddy Fork slopes about 1 ft/mile. The steeper slope of Puppy Creek probably means higher velocities, which could limit the density of benthic algae.

Dr. Stevenson examined percent cover by filamentous green algae in addition to benthic algae density. I was not able to replicate his presentation of these data (Figure 2.21 in his May 2008 report), but relying on his presentation, it appears that most stations had less than 30 percent cover. Reading from his graph, I estimate that 30 percent was exceeded at only 4 of 69 stations in 2006 and 27 of 70 stations in 2007. Not being able to replicate his presentation, I was unsure of the validity of the dataset in my possession and did not attempt to locate the high percent cover stations, but the density data suggest they would likely be in small tributaries downstream of WWTPs.

3.4 THE FREQUENCY OF DISSOLVED OXYGEN CRITERIA VIOLATIONS IN THE ILLINOIS RIVER ARE MINIMAL AND CAN NOT BE CONNECTED TO ANY ONE LAND USE

Drs. Cooke and Welch argue that low levels of dissolved oxygen have a strong negative impact on ecosystems of the water bodies of the Illinois River Watershed, and that much of the reduction in dissolved oxygen levels can be traced to land application of poultry litter. Dissolved oxygen data collected throughout the watershed refute this assertion.

Oklahoma regulations consider a stream to support the designated beneficial use of a cool water aquatic community if “no more than 10% of the samples from a stream are less than the screening level for DO” (OWRB 2008). As Figure 3-5 illustrates, for 2004-2007, the standard was met; only 3.4% of summer dissolved oxygen measurements, and 3.8% of dissolved oxygen measurements taken during the remainder of the year were below the associated criteria.

Of the 171 river and stream miles of the Illinois River Watershed that Oklahoma lists as not meeting water quality standards, only a 1.6 mile stretch of Flint Creek is listed as impaired due to dissolved oxygen (OWRB 2008). Nine potential sources are listed for the dissolved oxygen impairment of this stream segment.

Illinois River Watershed stream locations with sufficient dissolved oxygen data to assess water quality during 2004-2007 are indicated on Figure 3-6.[20] In 2007, 11% of the dissolved oxygen readings at the Flint Creek location were below the criteria. All other locations assessed had fewer than ten percent of the dissolved oxygen readings below the criteria for each year of the assessment. Land uses are also indicated on this map, and as can be seen, the majority of the land draining to locations with reduced dissolved oxygen is classified as deciduous forest or developed open space.

These data showing minimal dissolved oxygen violations, and the multiple potential sources of the dissolved oxygen impairments listed by the Oklahoma DEQ do not support the conclusion that poultry litter has impacted oxygen levels in the Illinois River Watershed.

3.5 THE FISHERIES IN THE ILLINOIS RIVER IN OKLAHOMA ARE NOT DAMAGED

In his report, Dr. Jan Stevenson evaluated fisheries in the Illinois River Watershed, from 37 locations in Arkansas and Oklahoma. His stated objective was “to document the injuries of fish species composition that are related to poultry house activities and nutrient pollution”

(Stevenson 2008; Section 4.1, p. 37). However, the analysis presented in his report fails to assess if the fisheries are actually injured, let alone injured due to poultry litter application and/or nutrient pollution.

Pollutants and other environmental stresses may simplify ecosystems by reducing the number of species present and by shifting the relative abundances of the surviving populations toward dominance by stress resistant species (Odum 1969; Woodwell 1970). The data collected in 2007 was intended to provide a basis to assess overall fish composition and abundance.[21] Most study sites contained species expected to occur within streams in the Ozark Highlands Ecoregion (with percids, cyprinids, and centrarchids typically most abundant [Dauwalter et al. 2003; Table 3-1]). The most common species collected in 2007 from the 37 Plaintiffs' locations were fluvial specialists such as stonerollers (*Campostoma spp*), cardinal shiner (*Luxilus cardinalis*), orangethroat darter (*Etheostoma spectabile*), and banded sculpin (*Cottus carolinae*). These four stream dwelling species prefer clear gravel bottom streams and require flowing water during some portion of their life history. Additionally, cardinal shiner is reported as one of the most intolerant fishes in Oklahoma of degradation to both water quality and habitat (Jester et al. 1992). Therefore, the presence of the cardinal shiner would indicate that water quality is not degraded. This species accounted for more than 2% of the overall abundance in 27 out of 37 locations (73%), and averaged 14% of the abundance at all locations (Table 3-1).

The overall composition and representativeness of species at each location provide additional insights regarding fishery health. We calculated Shannon-Weiner diversity and evenness for each location. Diversity values ranged from 1.01 to 2.58 with the two reference sites (Little Lee Creek RS-10003 and RS-10004)[22] at 2.09 and 2.11, respectively (Table 3-1). The lower diversity values, which may suggest some impact or may be due to smaller order streams being less diverse, are scattered throughout the watershed with no evident spatial patterns (Figure 3-7). Evenness was calculated to assess the relative spread of species and

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[20] Only locations with at least eight records in at least two years were considered. In addition, to ensure year-round oxygen status, only locations with at least one DO records in at least 3 quarters (three-month periods) were considered.

[21] Note: not all data used in this analysis were provided from the Plaintiffs' laboratory sheets. Additional data were used from Stevenson's considered materials; specifically: "Fish analysis.mdb" and "Database CDM 20080518.mdb."

evaluate if sites were dominated by one species. Values can range from zero for sites with one species dominant to one for sites were all species are found in equal numbers. Within the Illinois River Watershed, evenness ranged from 0.369 to 0.917; with values at the two reference sites of 0.753 and 0.656 (Table 3-1). While a few sites were dominated by one or two species, the majority of sites had fairly good representation of several stream species.

The index of biotic integrity (IBI) is a valuable metric that was developed to provide a straightforward and relatively quick method to assess local stream conditions based on the fish community (Karr et al. 1986). Fish integrate many trophic levels, providing a broad view of the biological community. The IBI is calculated and general descriptions given to each range of scores (e.g., good, fair, poor; see Chadwick 2009 for complete description of the IBI).

While initially developed for Midwestern streams, the IBI has been modified for several ecoregions throughout the United States, Mexico, and Europe. Recently, Dauwalter et al. (2003) developed an IBI for the Ozark Highlands Ecoregion in Arkansas. After review of the model, it was applied to the 37 locations in the Illinois River Watershed sampled in 2007. The final IBI is based on seven metrics representing taxonomic, trophic, reproductive, and health characteristics of fish asssemblages (Dauwalter et al. 2003).[23] Most of the final metrics were most significantly correlated with nutrients, chloride, land use, road densities, and sedimentation (Dauwalter et al. 2003), and should provide a robust method for assessing overall integrity.

Results of the IBI analysis within the Illinois River Watershed indicate most sites are in good condition (Table 3-1 and Figure 3-8). The majority of the sites rated as “good” are found in Oklahoma. To further evaluate the IBI score, comparisons were made between the IBI and local watershed characteristics, including:

- subwatershed area (Figure 3-9);
- poultry house density (Figure 3-10);
- road density (Figure 3-11);

[22] Note: the two reference sites are located outside of the Illinois River watershed.

- percent developed area (Figure 3-12);
- percent forested area (Figure 3-13);
- percent pasture area (Figure 3-14);
- density of WWTP discharges (Figure 3-15);
- distance to nearest road (Figure 3-16);
- distance to nearest urban land use classification (Figure 3-17); and
- distance to nearest poultry house (Figure 3-18).

There was no statistically significant relationship between the IBI value and any of these variables. For stations that had values below the minimum value for good scores (less than 60), points were scattered along the x-axis, rather than being clumped around any one value.

In summary, the fish community within the Illinois River Watershed is not highly degraded due to water quality impacts. While diversity is low in some locations, this is not unexpected due to the size of the streams (smaller streams will support fewer species). Stevenson also observed a direct relationship between fish species number and watershed size with fewer species in smaller watersheds (Stevenson 2008, Section 4.3.2.1., p. 40). There are limited data available on habitat parameters, so habitat quality can not be assessed at this time. However, it is possible that sites with lower IBI and/or diversity index scores may be more impacted by habitat availability than water quality degradation. Jester et al. (1992) reported that the majority of Oklahoma fish species are more sensitive to habitat degradation than they are to water quality degradation. Finally, the protocol used to sample fish may underestimate the diversity of fish within the watershed. Electrofishing consisted of sampling a habitat unit (e.g., riffle, pool) for three minutes (five minutes for boat shocking) and collecting stunned fish. In some cases, it appears that a second or third one- to three-minute period was sampled, although the exact protocols for this were not defined in the Standard Operating Procedures (SOP). It is fairly remarkable that the diversity within the watershed is as high as it is based on the low effort expended sampling each location. Diversity likely would be higher if more effort was expended

[23] Note: metric number 2 – percent with black spot or anomaly - was excluded due to insufficient data in the database.

at each site, especially in terms of the larger fish that more easily escape capture in a short period of time.

Table 3-1. Summary of species composition in the Illinois River Watershed based on the Plaintiff's 2007 data.

Creek Name	State	Location	Name	Count	Percent	Stream Order	SW Diversity	SW Evenness	IBI Score	IBI Description
Ballard Creek	AR	RS-399	Campostoma spp.	298	73.0	3	1.03	0.447	57	Fair
		RS-399	Etheostoma spectabile	42	10.3					
		RS-399	Luxilus cardinalis	25	6.1					
		RS-399	Lepomis cyanellus	17	4.2					
		RS-399	Phoxinus erythrogaster	14	3.4					
		RS-399	Other (5 spp)	12	2.9					
	OK	BS-62A	Campostoma spp.	192	28.6	3	1.95	0.704	78	Good
		BS-62A	Cottus carolinae	127	18.9					
		BS-62A	Luxilus cardinalis	127	18.9					
		BS-62A	Etheostoma spectabile	84	12.5					
		BS-62A	Lepomis megalotis	62	9.2					
		BS-62A	Other (9 spp)	33	4.9					
		BS-62A	Noturus exilis	24	3.6					
		BS-62A	Lepomis macrochirus	23	3.4					
Flint Creek	AR	RS-160	Cottus carolinae	148	46.5	4	1.64	0.747	63	Good
		RS-160	Phoxinus erythrogaster	59	18.6					
		RS-160	Semotilus atromaculatus	36	11.3					
		RS-160	Etheostoma flabellare	19	6.0					
		RS-160	Campostoma spp.	17	5.3					
		RS-160	Etheostoma spectabile	16	5.0					
		RS-160	Catostomus commersoni	15	4.7					
		RS-160	Other (2 spp)	8	2.5					
	OK	RS-902	Cottus carolinae	117	35.2	4	1.74	0.641	74	Good
		RS-902	Campostoma spp.	102	30.7					
		RS-902	Luxilus cardinalis	45	13.6					
		RS-902	Other (9 spp)	23	6.9					
		RS-902	Noturus exilis	20	6.0					
		RS-902	Etheostoma spectabile	18	5.4					
		RS-902	Micropterus dolomieu	7	2.1					
		RS-421	Etheostoma spectabile	221	45.6	4	1.62	0.614	75	Good
		RS-421	Campostoma spp.	99	20.4					
		RS-421	Luxilus cardinalis	60	12.4					
		RS-421	Noturus exilis	45	9.3					
		RS-421	Semotilus	23	4.7					

Creek Name	State	Location	Name	Count	Percent	Stream Order	SW Diversity	SW Evenness	IBI Score	IBI Description
			atromaculatus							
		RS-421	Etheostoma punctulatum	20	4.1					
		RS-421	Other (8 spp)	17	3.5					
Upper Illinois River	AR	RS-234	Campostoma spp.	320	39.0	3	1.96	0.678	68	Good
		RS-234	Luxilus cardinalis	142	17.3					
		RS-234	Lepomis megalotis	94	11.5					
		RS-234	Other (11 spp)	75	9.1					
		RS-234	Lepomis cyanellus	70	8.5					
		RS-234	Etheostoma spectabile	65	7.9					
		RS-234	Pimephales notatus	36	4.4					
		RS-234	Etheostoma blennioides	18	2.2					
Middle Illinois River	OK	RS-757	Luxilus cardinalis	229	32.0	6	2.16	0.635	58	Fair
		RS-757	Lepomis megalotis	192	26.9					
		RS-757	Other (21 spp)	76	10.6					
		RS-757	Moxostoma erythrurum	68	9.5					
		RS-757	Lepomis macrochirus	37	5.2					
		RS-757	Pimephales notatus	33	4.6					
		RS-757	Dorosoma cepedianum	26	3.6					
		RS-757	Campostoma spp.	22	3.1					
		RS-757	Lepomis cyanellus	17	2.4					
		RS-757	Micropterus punctulatus	15	2.1					
Lower Illinois River	OK	RS-433A	Luxilus cardinalis	401	64.3	6	1.52	0.471	70	Good
		RS-433A	Notropis boops	66	10.6					
		RS-433A	Other (19 spp)	64	10.3					
		RS-433A	Lepomis megalotis	33	5.3					
		RS-433A	Campostoma spp.	26	4.2					
		RS-433A	Micropterus dolomieu	19	3.0					
		RS-433A	Pimephales notatus	15	2.4					
		RS-654	Pimephales notatus	153	18.1	6	2.58	0.767	62	Good
		RS-654	Notropis boops	127	15.1					
		RS-654	Luxilus cardinalis	94	11.2					
		RS-654	Lepomis megalotis	92	10.9					
		RS-654	Other (18 spp)	82	9.7					
		RS-654	Dorosoma cepedianum	64	7.6					
		RS-654	Dorosoma petenense	61	7.2					
		RS-654	Hypentelium nigricans	52	6.2					
		RS-654	Notropis nubilus	33	3.9					
		RS-654	Campostoma spp.	32	3.8					

Creek Name	State	Location	Name	Count	Percent	Stream Order	SW Diversity	SW Evenness	IBI Score	IBI Description
		RS-654	Lepomis macrochirus	28	3.3					
		RS-654	Moxostoma erythrurum	25	3.0					
Trib to Lower Illinois River	OK	RS-604	Luxilus cardinalis	587	51.2	4	1.2	0.502	69	Good
		RS-604	Etheostoma spectabile	305	26.6					
		RS-604	Campostoma spp.	209	18.2					
		RS-604	Other (8 spp)	46	4.0					
Unnamed tributary to Illinois River	OK	RS-772	Cottus carolinae	187	53.4	3	1.34	0.642	53	Fair
		RS-772	Phoxinus erythrogaster	81	23.1					
		RS-772	Campostoma spp.	30	8.6					
		RS-772	Semotilus atromaculatus	30	8.6					
		RS-772	Etheostoma spectabile	13	3.7					
		RS-772	Other (3 spp)	9	2.6					
Bush Creek	AR	BS-HF22	Phoxinus erythrogaster	69	24.3	3	2.11	0.8	68	Good
		BS-HF22	Campostoma spp.	51	18.0					
		BS-HF22	Cottus carolinae	49	17.3					
		BS-HF22	Etheostoma spectabile	42	14.8					
		BS-HF22	Semotilus atromaculatus	21	7.4					
		BS-HF22	Noturus exilis	13	4.6					
		BS-HF22	Other (4 spp)	11	3.9					
		BS-HF22	Etheostoma punctulatum	9	3.2					
		BS-HF22	Etheostoma flabellare	7	2.5					
		BS-HF22	Lepomis cyanellus	6	2.1					
		BS-HF22	Luxilus cardinalis	6	2.1					
Cincinnati Creek	AR	RS-392	Phoxinus erythrogaster	124	38.5	3	1.7	0.661	68	Good
		RS-392	Etheostoma spectabile	70	21.7					
		RS-392	Campostoma spp.	54	16.8					
		RS-392	Cottus carolinae	30	9.3					
		RS-392	Luxilus cardinalis	25	7.8					
		RS-392	Other (8 spp)	19	5.9					
		RS-386	Etheostoma spectabile	130	29.3		1.8	0.752	77	Good
		RS-386	Campostoma spp.	99	22.3	3				

Creek Name	State	Location	Name	Count	Percent	Stream Order	SW Diversity	SW Evenness	IBI Score	IBI Description
		RS-386	Luxilus cardinalis	79	17.8					
		RS-386	Etheostoma punctulatum	61	13.8					
		RS-386	Cottus carolinae	39	8.8					
		RS-386	Semotilus atromaculatus	11	2.5					
		RS-386	Noturus exilis	10	2.3					
		RS-386	Phoxinus erythrogaster	10	2.3					
		RS-386	Other (3 spp)	4	0.9					
		BS-68	Campostoma spp.	169	29.9	4	1.69	0.641	75	Good
		BS-68	Luxilus cardinalis	168	29.7					
		BS-68	Etheostoma spectabile	117	20.7					
		BS-68	Noturus exilis	54	9.6					
		BS-68	Other (8 spp)	23	4.1					
		BS-68	Etheostoma punctulatum	17	3.0					
		BS-68	Semotilus atromaculatus	17	3.0					
Fly Creek	AR	BS-35	Campostoma spp.	344	45.1	3	1.41	0.551	74	Good
		BS-35	Etheostoma spectabile	257	33.7					
		BS-35	Luxilus cardinalis	76	10.0					
		BS-35	Other (8 spp)	40	5.2					
		BS-35	Cottus carolinae	26	3.4					
		BS-35	Lepomis cyanellus	20	2.6					
Muddy Fork	AR	RS-233	Lepomis megalotis	75	24.0	4	2.48	0.827	65	Good
		RS-233	Etheostoma spectabile	35	11.2					
		RS-233	Campostoma spp.	33	10.5					
		RS-233	Luxilus cardinalis	29	9.3					
		RS-233	Lepomis cyanellus	26	8.3					
		RS-233	Pimephales notatus	20	6.4					
		RS-233	Other (8 spp)	19	6.1					
		RS-233	Etheostoma blennioides	19	6.1					
		RS-233	Cottus carolinae	18	5.8					
		RS-233	Lepomis macrochirus	11	3.5					
		RS-233	Noturus exilis	10	3.2					
		RS-233	Etheostoma zonale	9	2.9					
		RS-233	Lepomis gulosus	9	2.9					
Spring Creek	AR	RS-121	Etheostoma spectabile	63	27.2	4	1.95	0.76	54	Fair
		RS-121	Campostoma spp.	45	19.4					
		RS-121	Luxilus cardinalis	43	18.5					
		RS-121	Noturus exilis	34	14.7					

Creek Name	State	Location	Name	Count	Percent	Stream Order	SW Diversity	SW Evenness	IBI Score	IBI Description
		RS-121	Lepomis megalotis	15	6.5					
		RS-121	Lepomis cyanellus	12	5.2					
		RS-121	Other (6 spp)	11	4.7					
		RS-121	Lepomis macrochirus	9	3.9					
Baron Fork	OK	RS-682	Cottus carolinae	181	51.4	4	1.53	0.597	66	Good
		RS-682	Campostoma spp.	77	21.9					
		RS-682	Etheostoma spectabile	27	7.7					
		RS-682	Luxilus cardinalis	23	6.5					
		RS-682	Other (7 spp)	17	4.8					
		RS-682	Noturus exilis	16	4.5					
		RS-682	Etheostoma punctulatum	11	3.1					
		RS-649	Campostoma spp.	410	37.2	6	1.83	0.574	78	Good
		RS-649	Luxilus cardinalis	334	30.3					
		RS-649	Other (18 spp)	100	9.1					
		RS-649	Etheostoma spectabile	92	8.4					
		RS-649	Cottus carolinae	83	7.5					
		RS-649	Noturus exilis	57	5.2					
		RS-649	Lepomis megalotis	25	2.3					
Bidding Springs	OK	RS-706	Luxilus cardinalis	68	23.7	2	2.1	0.714	77	Good
		RS-706	Etheostoma flabellare	64	22.3					
		RS-706	Campostoma spp.	50	17.4					
		RS-706	Etheostoma spectabile	29	10.1					
		RS-706	Lepomis cyanellus	26	9.1					
		RS-706	Other (11 spp)	18	6.3					
		RS-706	Fundulus olivaceus	17	5.9					
		RS-706	Cottus carolinae	9	3.1					
		RS-706	Semotilus atromaculatus	6	2.1					
Caney Creek	OK	RS-728	Campostoma spp.	527	48.1	2	1.04	0.578	61	Good
		RS-728	Etheostoma spectabile	417	38.0					
		RS-728	Phoxinus erythrogaster	142	13.0					
		RS-728	Other (3 spp)	10	0.9					
		RS-704	Cottus carolinae	304	37.0	4	1.56	0.65	61	Good
		RS-704	Campostoma spp.	214	26.0					
		RS-704	Phoxinus erythrogaster	168	20.4					
		RS-704	Luxilus cardinalis	77	9.4					
		RS-704	Other (6 spp)	31	3.8					
		RS-704	Etheostoma spectabile	28	3.4					

Creek Name	State	Location	Name	Count	Percent	Stream Order	SW Diversity	SW Evenness	IBI Score	IBI Description
Evansville Creek	OK	RS-693	Campostoma spp.	304	47.7	4	1.54	0.602	72	Good
		RS-693	Etheostoma spectabile	159	25.0					
		RS-693	Lepomis megalotis	54	8.5					
		RS-693	Lepomis cyanellus	41	6.4					
		RS-693	Luxilus cardinalis	33	5.2					
		RS-693	Noturus exilis	24	3.8					
		RS-693	Other (7 spp)	22	3.5					
Little Lee Creek	OK	RS-10003	Campostoma spp.	105	33.2		2.09	0.753	96	Reference
		RS-10003	Luxilus cardinalis	56	17.7					
		RS-10003	Etheostoma spectabile	36	11.4					
		RS-10003	Lepomis megalotis	31	9.8					
		RS-10003	Etheostoma flabellare	24	7.6					
		RS-10003	Noturus exilis	15	4.7					
		RS-10003	Other (6 spp)	14	4.4					
		RS-10003	Micropterus dolomieu	13	4.1					
		RS-10003	Etheostoma blennioides	8	2.5					
		RS-10003	Lepomis cyanellus	7	2.2					
		RS-10003	Semotilus atromaculatus	7	2.2					
		RS-10004	Lepomis megalotis	181	26.2		2.11	0.656	96	Reference
		RS-10004	Luxilus cardinalis	178	25.7					
		RS-10004	Campostoma spp.	98	14.2					
		RS-10004	Etheostoma flabellare	85	12.3					
		RS-10004	Other (18 spp)	79	11.4					
		RS-10004	Noturus exilis	35	5.1					
		RS-10004	Etheostoma spectabile	19	2.7					
		RS-10004	Etheostoma blennioides	17	2.5					
Park Hill Branch	OK	RS-518	Campostoma spp.	751	77.6	3	1.02	0.369	64	Good
		RS-518	Other (11 spp)	74	7.6					
		RS-518	Etheostoma spectabile	63	6.5					
		RS-518	Cottus carolinae	29	3.0					
		RS-518	Semotilus	27	2.8					

Creek Name	State	Location	Name	Count	Percent	Stream Order	SW Diversity	SW Evenness	IBI Score	IBI Description
			atromaculatus							
		RS-518	Etheostoma flabellare	23	2.4					
Peacheater Creek	OK	BS-208	Luxilus cardinalis	47	19.7	4	2.22	0.82	76	Good
		BS-208	Cottus carolinae	46	19.3					
		BS-208	Campostoma spp.	30	12.6					
		BS-208	Semotilus atromaculatus	28	11.8					
		BS-208	Etheostoma flabellare	25	10.5					
		BS-208	Etheostoma spectabile	17	7.1					
		BS-208	Phoxinus erythrogaster	15	6.3					
		BS-208	Nocomis asper	11	4.6					
		BS-208	Etheostoma punctulatum	7	2.9					
		BS-208	Noturus exilis	6	2.5					
		BS-208	Other (5 spp)	6	2.5					
Peavine Creek	OK	RS-657	Phoxinus erythrogaster	258	30.6	3	1.67	0.631	69	Good
		RS-657	Cottus carolinae	252	29.9					
		RS-657	Campostoma spp.	148	17.5					
		RS-657	Etheostoma spectabile	116	13.7					
		RS-657	Other (9 spp)	47	5.6					
		RS-657	Luxilus cardinalis	23	2.7					
Sager Creek	OK	BS-HF04	Etheostoma spectabile	179	53.8	3	1.52	0.613	80	Reference
		BS-HF04	Semotilus atromaculatus	54	16.2					
		BS-HF04	Campostoma spp.	24	7.2					
		BS-HF04	Cottus carolinae	23	6.9					
		BS-HF04	Etheostoma punctulatum	19	5.7					
		BS-HF04	Luxilus cardinalis	19	5.7					
		BS-HF04	Noturus exilis	10	3.0					
		BS-HF04	Other (5 spp)	5	1.5					
Scraper Hollow Creek	OK	RS-667	Phoxinus erythrogaster	45	35.2	3	1.73	0.83	57	Fair
		RS-667	Cottus carolinae	26	20.3					
		RS-667	Semotilus atromaculatus	26	20.3					
		RS-667	Etheostoma spectabile	10	7.8					
		RS-667	Campostoma spp.	7	5.5					

Creek Name	State	Location	Name	Count	Percent	Stream Order	SW Diversity	SW Evenness	IBI Score	IBI Description
		RS-667	Lepomis cyanellus	6	4.7					
		RS-667	Noturus exilis	6	4.7					
		RS-667	Other (1 spp)	2	1.6					
Shell Branch	OK	RS-793	Phoxinus erythrogaster	23	20.2	2	1.91	0.917	76	Good
		RS-793	Etheostoma punctulatum	20	17.5					
		RS-793	Etheostoma spectabile	19	16.7					
		RS-793	Cottus carolinae	18	15.8					
		RS-793	Luxilus cardinalis	18	15.8					
		RS-793	Etheostoma flabellare	9	7.9					
		RS-793	Noturus exilis	6	5.3					
		RS-793	Other (1 spp)	1	0.9					
Tahlequah Creek	OK	RS-630	Etheostoma flabellare	290	64.3	4	1.12	0.694	62	Good
		RS-630	Phoxinus erythrogaster	69	15.3					
		RS-630	Campostoma spp.	35	7.8					
		RS-630	Etheostoma spectabile	34	7.5					
		RS-630	Semotilus atromaculatus	23	5.1					
		RS-578	Campostoma spp.	291	40.5	4	1.66	0.556	74	Good
		RS-578	Luxilus cardinalis	230	32.0					
		RS-578	Etheostoma spectabile	67	9.3					
		RS-578	Other (14 spp)	50	7.0					
		RS-578	Noturus exilis	36	5.0					
		RS-578	Cottus carolinae	25	3.5					
		RS-578	Etheostoma flabellare	20	2.8					
Tate Paris Creek	OK	RS-770	Etheostoma flabellare	150	36.2	3	1.69	0.66	78	Good
		RS-770	Etheostoma spectabile	112	27.1					
		RS-770	Luxilus cardinalis	57	13.8					
		RS-770	Campostoma spp.	50	12.1					
		RS-770	Other (7 spp)	21	5.1					
		RS-770	Etheostoma punctulatum	13	3.1					
		RS-770	Semotilus atromaculatus	11	2.7					
Tyner Creek	OK	RS-541	Phoxinus erythrogaster	226	52.3	3	1.01	0.628	53	Fair
		RS-541	Cottus carolinae	157	36.3					
		RS-541	Etheostoma flabellare	42	9.7					
		RS-541	Other (2 spp)	7	1.6					

Creek Name	State	Location	Name	Count	Percent	Stream Order	SW Diversity	SW Evenness	IBI Score	IBI Description
		RS-548	Cottus carolinae	292	47.9	5	1.53	0.614	62	Good
		RS-548	Phoxinus erythrogaster	128	21.0					
		RS-548	Campostoma spp.	86	14.1					
		RS-548	Etheostoma flabellare	41	6.7					
		RS-548	Luxilus cardinalis	26	4.3					
		RS-548	Semotilus atromaculatus	15	2.5					
		RS-548	Other (6 spp)	21	3.4					

4.5 THE FISHERIES IN LAKE TENKILLER ARE NOT DAMAGED

Lake Tenkiller has catch-limits in place to increase or decrease the catch rate or sizes of different species targeted by anglers. In addition, lake levels are primarily managed for flood control purposes, which can lead to stress or recruitment failure for some species depending on the timing and extremity of water level fluctuations.

The Oklahoma Department of Wildlife Conservation (ODWC) actively manages the bass fishery in Lake Tenkiller, as well as other lakes and reservoirs in the state. The lake has been stocked since inundation with largemouth bass (Florida strain), walleye, striped bass, rainbow trout, threadfin shad (to provide a forage base for bass), and more recently (1990-1991) with smallmouth bass (non-native Tennessee Lake strain) (ODWC 1989, 2003a). Periodic electrofishing surveys are conducted at locations within the riverine, transitional, and lacustrine portions of the lake to assess the bass and other sport fish populations. Based on those studies, Lake Tenkiller typically ranks in the top five in Oklahoma in the number of largemouth bass caught per hour in reservoirs >1,000 acres (ODWC 2003b, 2006). According to ODWC, high quality lakes produce at least 60 bass per hour of electrofishing with 15 or more of those fish at least 14 inches (356 mm) long. Lake Tenkiller was in the high quality category for every year data were available between 1993 and 2006 (Table 4-2; Figure 4-10). In comparison, Broken Bow was below average in 1993-1996 and 2006; in the quality category in 1997; high quality in 2000, 2001.

Table 4-2. Summary of Oklahoma Department of Wildlife Conservation spring largemouth bass electrofishing surveys 1993-2006.[1]

Year	Bass Abundance (#/hour)	Number Bass Over 14 inches per hour	Heaviest Fish (lbs)	Notes
Lake Tenkiller				
1993	119.1	36.7	6.6	
1994	114	42	6.9	
1996	189	75	6.2	
1997	130	48	7.3	
1999	145	79.7	6.0	
2001	110	31	3.4	2000 winterkill of threadfin shad; largemouth bass virus summer of 2000
2002	64	27	4.1	
2003	77.5	21	4.9	
2005	112.3	39.3	5.9	
2006	69	35	4.0	Low lake levels made sampling difficult so numbers may be unnaturally low
Broken Bow				
1993	37.9	13.4	6.4	
1994	33	5	3.8	
1996	27	7	5.2	
1997	55.6	17.6	6.0	
1999	Not Sampled			
2001	72	22	2.6	
2002	72	22	2.6	
2003	Not Sampled			
2005	Not Sampled			
2006	43	8	5.0	

[1] *Data downloaded from www.wildlifedepartment.com on June 12, 2008.*
High Quality Fishery: 60 or more bass per hour of electrofishing with 15 or more bass at least 14 inches (356 mm) in length.
Quality Fishery: 40 or more bass per hour of electrofishing with 10 or more bass at least 14 inches (356 mm) in length.

Lake Tenkiller has been cited as one of the "state's premier fisheries" with fishing for black bass, crappie, and catfish (McNeff 2008). The black bass (i.e., smallmouth, largemouth, and spotted bass) fishery in Lake Tenkiller is dominated by largemouth bass, with smaller numbers of spotted bass and smallmouth bass (Table 4-3).[25] Largemouth bass typically prefer

[25] Note: not all data used in this analysis were provided from the Plaintiffs' laboratory sheets. Additional data were used from Stevenson's considered materials; specifically: "Database CDM 20080518.mdb."

warmer, quieter waters of lakes and large streams compared to smallmouth bass and spotted bass. The large number of coves and backwater areas with vegetative growth are most suitable to largemouth bass. Spotted bass may do well in some clear lakes; however, they are best adapted for small, clear, spring-fed streams (Miller and Robison 2004). Smallmouth bass also prefer cool, clear rocky streams with spawning occurring in flowing waters (Miller and Robison 2004).

In 1987, ODWC modified the black bass (largemouth, smallmouth, spotted bass) fishing catch-limits due to several years of successful recruitment. The limit was changed from a 14 inch (356 mm) minimum size to a slot limit of 13 to 16 inches (330 to 406 mm), with a creel limit of 6 fish per day (combined) above or below this size range. This is typically done in lakes to encourage anglers to harvest the smaller fish that are competing for available forage, essentially thinning out the population so that the remaining fish can grow larger, faster. The slot limit can be used on lakes with numerous years of successful recruitment and an abundance of juveniles. In Lake Tenkiller, bass have much more reproductive success when spring lake levels are in the flood pool, particularly during spawning and rearing (May 15 – July 1). In years when water levels are lower, black bass recruitment is expected to be much less. The catch-limits were changed again in 1997 for spotted bass with no minimum length limit and a creel limit of 15 fish per day, to encourage harvest of this species (ODWC 2003a). In 1997, the smallmouth and largemouth bass limits were not changed. In 2009, catch and size limits were eliminated for spotted bass statewide; limits were unchanged for smallmouth and largemouth bass (ODWC 2009a)

Based on electrofishing data from 1991 through 1997 (ODWC), black bass condition has generally been healthy (i.e., condition factor greater than 1.0; Table 4-3). Largemouth bass numbers declined slightly lake wide from 1991 to 1997, with spotted bass slightly increasing over that time frame and smallmouth bass remaining low (Table 4-3).

Table 4-3. Lake Tenkiller spring (April-May) electrofishing sampling - bass condition factor.

Zone	Year	Largemouth Bass		Smallmouth Bass		Spotted Bass	
		Condition Factor	Count	Condition Factor	Count	Condition Factor	Count
Riverine	1991	1.25	319	1.12	2	1.28	17
	1992	1.24	352	1.21	1	1.27	29
	1993	1.28	187	0.98	1	1.22	12
	1994	Not Sampled					
	1996	1.32	125	*	*	1.27	9
	1997	1.31	174	*	*	1.36	10
Transitional	1991	1.26	353	*	*	1.33	55
	1992	1.31	358	1.12	2	1.37	52
	1993	1.30	280	*	*	1.26	51
	1994	1.25	254	1.27	1	1.20	52
	1996	1.28	143	*	*	1.30	11
	1997	1.33	185	1.36	3	1.30	57
Lacustrine	1991	1.30	156	1.19	1	1.27	14
	1992	1.25	149	1.33	1	1.11	24
	1993	1.23	51	*	*	1.12	4
	1994	Not Sampled					
	1996	1.36	297	*	*	1.35	18
	1997	1.23	202	1.34	1	1.11	45
Lake wide	1991	1.27	828	1.14	3	1.31	86
	1992	1.27	859	1.20	4	1.28	105
	1993	1.29	518	0.98	1	1.24	67
	1994	1.25	254	1.27	1	1.20	52
	1996	1.33	565	*	*	1.31	38
	1997	1.29	561	1.36	4	1.23	112

** Species not captured during year.*
Data from Oklahoma Department of Wildlife Conservation.
Condition factor = (Wt x 100,000)/(TL^3)

Based on the large data set available for largemouth bass and the management focus on this species, additional analyses were conducted to assess the overall health of this fishery based on length frequency plots and condition factor from the 1991-1997 ODWC dataset. On a lake wide basis, largemouth bass mean length and weight in spring increased from 1991 to 1997 (Table 4-4). This may be the result of the slot limit placed on black bass in 1987 (Smith 1988).

Table 4-4. Lake Tenkiller spring (April-May) electrofishing sampling - largemouth bass.

Zone	Year	Mean TL (mm)	S.D. TL	Max TL (mm)	Mean Wt (g)	S.D. Wt		Mean Condition Factor	Count
Riverine	1991	271	85	560	363	431	3147	1.25	319
	1992	276	83	530	349	348	2041	1.24	352
	1993	292	97	520	462	445	2381	1.28	187
	1994	Not Sampled							
	1996	292	96	520	448	446	2080	1.31	126
	1997	321	93	572	559	504	2940	1.28	178
Transitional	1991	271	85	560	363	431	3147	1.25	319
	1992	276	83	530	349	348	2041	1.24	352
	1993	292	97	520	462	445	2381	1.28	187
	1994	Not Sampled							
	1996	292	96	520	448	446	2080	1.31	126
	1997	321	93	572	559	504	2940	1.28	178
Lacustrine	1991	264	79	510	326	353	2041	1.30	156
	1992	293	82	535	424	305	1701	1.07	174
	1993	303	77	545	425	363	2155	1.23	51
	1994	Not Sampled							
	1996	311	98	556	544	483	2620	1.36	297
	1997	300	104	920	481	905	12000	1.22	203
Lakewide	1991	267	82	560	340	390	3147	1.27	828
	1992	286	82	560	383	335	2381	1.23	884
	1993	294	97	545	469	458	2807	1.29	518
	1994	304	93	750	472	561	6237	1.25	254
	1996	297	97	556	478	456	2620	1.33	566
	1997	314	97	920	536	669	12000	1.27	567

Note: Records with negative weight values were removed from the analysis.
Data from Oklahoma Department of Wildlife Conservation.
TL = total length; S.D. = standard deviation; Wt. = weight
Condition factor = (Wt x 100,000)/(TL^3)

An evaluation of length frequency provides an assessment of overall size structure in the lake. There is little difference in length frequency in largemouth bass among the three zones; therefore, length frequency was evaluated on a lake wide basis to provide a more robust analysis. From 1991 to 1997, it is apparent that the overall size structure has moved towards a more balanced population with more fish in the larger size classes in later years (Figure 4-11). As noted above, the largemouth bass fishery declined in overall numbers from 1991-1997, but through management of the fishery the remaining fish are larger and more evenly distributed, which was a focus of the lake management and implementation of slot limits.

Two additional metrics, commonly used in fisheries management to evaluate size structure are the proportional stock density (PSD) and relative stock density (RSD). The proportional stock density is calculated as:

$$\mathrm{PSD} = \frac{\text{number of fish} \geq \text{minimum quality length}}{\text{number of fish} \geq \text{minimum stock length}} \times 100$$

The relative stock density is calculated as:

$$\mathrm{RSD} = \frac{\text{number of fish} \geq \text{specified length}}{\text{number of fish} \geq \text{minimum stock length}} \times 100$$

Both PSD and RSD can range from 0 to 100 and are typically reported to the nearest whole number. Stock length has been defined as the approximate length at maturity, the minimum length effectively sampled by traditional fisheries gears, and the minimum length of fish that provide recreational value (Anderson and Neumann 1996). Quality length is defined as the minimum size fish most anglers like to catch. For largemouth bass, stock length is 8 in. (200 mm) and quality length is 12 in. (300 mm; Anderson and Neumann 1996). RSD was first used for largemouth bass with a specified length of 15 inches (380 mm) which represents the preferred minimum size and is referred to as RSD15 (Anderson and Neumann 1996). Two other size ranges can be used in the RSD, memorable minimum size and trophy minimum size. Based on data from the 1987 assessment, PSD was calculated as 60 and RSD15 was 17 for largemouth bass (ODWC 1989). In 1997, PSD was 66 and RSD15 was 31. The change in regulations in 1987 appeared to result in are higher proportion of larger fish by 1997 as intended. Balanced largemouth bass populations may have PSD values ranging from 40 to 70 (Anderson and Neumann 1996).

The largemouth bass population in Lake Tenkiller is the most abundant of the black bass; spotted bass makes up approximately 20% of the black bass population. The goal of management is to maintain the spotted bass population at 15% to 20% of the total black bass population (Smith 1988). Catch-limits were modified for spotted bass in 1997 with no minimum length limit and a creel limit of 15 fish per day to encourage more angling for this species (ODWC 2003a). Lake Tenkiller was recently included on a list of the Best Fishing Towns in America by *Field and Stream* (Deeter 2008). Tahlequah, Oklahoma was the focus with reference to the proximity of the town to prime largemouth bass fishing lakes, especially Lake Tenkiller.

A largemouth bass die off occurred in Lake Tenkiller in the summer of 2000 due to an outbreak of largemouth bass virus (ODWC 2003a). All largemouth bass tested in 2000 were infected with the virus while these numbers dropped in subsequent years with just over 11% of the tested fish infected in 2003 (ODWC 2003a). This may have reduced the population slightly, but it appears to be recovering. In addition, a winterkill of threadfin shad in winter 2000 resulted in a smaller forage base available for bass the following spring. This may have resulted in the slightly lower condition of bass as reported by ODWC (2003a).

While smallmouth bass may be a desirable species in the Lake Tenkiller black bass fishery, it is likely that the endemic smallmouth bass (Micropterus dolomieui velox) in the Illinois River Watershed is adapted for more of a riverine environment. The Neosho strain (*M. dolomieu velox*) of smallmouth bass present in the Illinois watershed represents one of the most isolated populations of the species (e.g., high genetic diversity; Oklahoma State University [OSU] 1994). Prior to the formation of Lake Tenkiller, spotted bass was the dominant bass within this section of the Illinois River (Paden 1948), with smallmouth bass in moderate numbers and largemouth bass least dominant. Following formation of Lake Tenkiller, the status of the smallmouth bass population in the lake was in doubt due to their habitat requirements (Hall 1953). Twenty five years later, a regional fisheries biologist indicated that there were no lakes in Oklahoma that he knew of where spotted bass adapted more successfully than largemouth bass when impounded (Smith 1978). Additionally, spotted bass generally adapt better than the smallmouth bass to impoundment conditions, but the largemouth bass are dominant (Smith 1978). Therefore, one would expect the bass fishery in Lake Tenkiller to be dominated by largemouth bass, followed by spotted bass, with smallmouth bass a minor component. Based on management reports through the 1980s, black bass management in Lake Tenkiller focused primarily on largemouth bass as the dominant black bass in the system.

Smallmouth bass of a non-native reservoir strain (Tennessee Lake strain) were stocked in 1990 and 1991 in an effort to develop a more robust smallmouth bass fishery based on a more lacustrine adapted strain. This effort was suspended following analysis of the genetic diversity in the native strain smallmouth bass (OSU 1994). This suspension was based on a study of the genetic distinctiveness of smallmouth bass in Oklahoma that found "..the Neosho and Ouachita forms of smallmouth bass are the most isolated populations of the species…and protein electrophorsis demonstrates that, genetically, the Neosho and Ouachita forms of smallmouth bass are the most distinctive of all populations of smallmouth bass….likely the result of a long history of isolation that probably dates to the last glaciation (10,000 years ago) or earlier" (OSU 1994). Based on those findings the authors recommended "…no stockings of non-native smallmouth bass in the Little, Neosho, and Illinois river systems or direct tributaries of the Arkansas River" (OSU 1994).

The assessment by Drs. Cooke and Welch on the habitat squeeze for smallmouth bass and spotted bass within Lake Tenkiller relies on a gross approximation of general habitat conditions within the main channel of the lake. Application of this throughout the entire lake (based on four open water sampling locations) to assess habitat availability for black bass does not account for life history strategies of these species. Black bass are a littoral zone species, occupying steep rocky shorelines or areas with macrophyte coverage, while the habitat squeeze model is based on water quality within the pelagic zone. The habitat squeeze model does not represent or account for the numerous refuges available within the littoral zone, especially at the mouths of tributaries and in coves. Smallmouth bass in lakes and reservoirs typically prefer drop-offs, rocky shoals, and wave swept littoral regions (Edwards et al. 1973; Hubert and Lackey 1980; Winemiller and Taylor 1987). Spotted bass also prefer areas with steep, rocky shorelines (McMahon et al. 1984). Adult black bass typically feed in the littoral zone, with smallmouth bass and spotted bass feeding on crustaceans and fish within the interstitial spaces in cobble and largemouth bass feeding primarily on prey found within vegetated habitats (Werner et al. 1977; McMahon et al. 1984; Weaver et al. 1997).

The morphology of Lake Tenkiller, with steep, rocky shoreline areas provides the necessary littoral zone habitat for smallmouth bass that would not be compromised by the open water hypoxia. The littoral zone in these areas is not likely to experience the oxygen depletion seen in the hypolimnion due to wind and wave action and fresh water inflow from tributaries. The presence of a healthy population of spotted bass (catch limits are currently set to encourage harvest of this species because their population is higher than fishery managers prefer) also indicates that there are refuges available for this species throughout the lake during the warmest summer months. An evaluation of littoral zone habitat availability and suitability, including temperature and dissolved oxygen fluctuations, would provide more suitable information to describe factors that may be influencing black bass populations within Lake Tenkiller.

In addition to black bass, several other sportfish are found in Lake Tenkiller including white bass and channel catfish. Channel catfish and white bass populations were assessed based on gillnetting surveys conducted by ODWC during November 1990, 1992, 1993, and 1996. Overall condition of both species was good with condition factors above 1.0 each year (Table 4-5). Based on the length frequency analysis, many of the white bass collected through the years are within the preferred size (minimum length 12 in; 300 mm) for anglers (Figure 4-12). For white bass, the preferred size range is 12 inches (300 mm) or greater total length, with memorable size 15 inches (380 mm) or greater, and trophy 18 inches (460 mm) or greater. Approximately 8% of the samples in 1991 were of trophy size, with lower percentages in subsequent years (Figure 4-12). Overall abundance of white bass was similar in all years to the range seen from 1978 to 1987 (113 to 265 individuals) (ODWC 1989).

Table 4-5. Lake Tenkiller November gillnet and research gillnet sampling summary.

Zone	Year	Mean TL (mm)	TL S.D.	Max TL (mm)	Mean Wt (g)	Wt S.D.	Max Wt (g)	Mean Condition Factor	Count*
Channel Catfish									
Riverine	1990	409	199	1050	873	925	4082	1.16	59
	1992	241	102	650	436	635	3990	1.00	119 (62)
	1993	268	108	525	354	447	2098	1.21	38
	1996	Not Sampled							
Transitional	1990	273	132	635	463	855	3402	0.96	19
	1992	291	75	414	353	298	940	1.11	24 (17)
	1993	224	86	550	195	331	2041	1.07	52
	1996	269	88	487	359	473	2040	1.06	27
Lacustrine	1990	356	130	765	832	1150	5897	1.16	28
	1992	243	88	420	550	452	1276	1.38	22 (9)
	1993	286	110	590	443	520	2835	1.25	52
	1996	300	94	600	429	523	2722	1.17	25
Lakewide	1990	371	179	1050	789	981	5897	1.13	106
	1992	249	98	650	432	566	3990	1.06	165 (88)
	1993	258	104	590	328	449	2835	1.17	142
	1996	284	91	600	393	494	2722	1.12	52
White Bass									
Riverine	1990	299	57	369	252	126	400	0.87	11
	1992	266	91	503	463	408	1644	1.10	46 (27)
	1993	234	87	500	191	232	1216	1.22	79
	1996	Not Sampled							
Transitional	1990	282	69	440	363	243	1021	1.36	18
	1992	315	135	630	820	840	2892	1.29	24 (17)
	1993	224	72	510	169	220	1382	1.10	228
	1996	286	93	550	422	411	2800	1.25	133
Lacustrine	1990	314	121	690	671	1135	6208	1.31	62
	1992	300	91	476	662	491	1758	1.35	50 (29)
	1993	263	103	670	355	513	4536	1.25	433
	1996	262	82	450	276	273	1042	1.05	132
Lakewide	1990	306	106	690	560	956	6208	1.27	91
	1992	290	102	630	625	574	2892	1.25	120 (73)
	1993	248	94	670	280	427	4536	1.20	740
	1996	274	88	550	349	356	2800	1.15	265

**Data from 1992 contained length data for all fish, but was missing weight data for a subset; weight count provided in parentheses. Data from Oklahoma Department of Wildlife Conservation.*
TL = total length; S.D. = standard deviation; Wt. = weight
Condition factor = (Wt x 100,000)/(TL3)

For channel catfish, many of the fish captured during the gillnetting surveys were within the stock (11 inches; 280 mm minimum total length) or quality size range (16 inches; 410 mm minimum total length) (Figure 4-13). In 1990, nearly 10% of the individuals were near memorable size (minimum length 28 inches; 710 mm), while in subsequent years, most were in the quality size class (16 inches; 410 mm) with a few in the preferred size class (24 inches; 610 mm) in subsequent years. This is a slight shift from 1987 when 42% were within the quality size class, indicating an overall smaller fish and likely younger population. There is no size limit on channel catfish within Lake Tenkiller with a maximum limit of 15 (channel and blue catfish combined) fish per day. Overall abundance is generally within the range reported from 1978 to 1987 (45 to 121 individuals) (ODWC 1989), and although being low in some years and slightly smaller in median length, is relatively balanced.

An overall assessment of species relative abundance based on a combination of seining data and gill net data also was conducted based on ODWC data. All species captured during the fall gillnetting in 1990, 1992, 1993, and 1996 were recorded and provide an overall assessment of species composition within the three zones of Lake Tenkiller (Riverine, Transitional, and Lacustrine). Zones were defined as provided in Cooke and Welch's May 2008 report. It is interesting to note, that from 1990 to 1996, white bass percent frequency from samples within the three zones increased from 10% to 30% to approximately 30% to 60% of the composition in 1993 and 1996 (Figure 4-14). White bass feed on threadfin shad which were stocked in Lake Tenkiller since as early as 1965 (ODWC 1989). In addition, gizzard shad numbers have been fairly high during this time period as well (Figure 4-14). Threadfin shad typically provide better forage of the two shad species, since they do not get as large and grow slower than gizzard shad, thereby spending more time as available prey. This increased forage base may have allowed for an increase in the white bass population.

Analysis of seining data obtained for June and July of 1990 and 1991 provides insight into the forage base and recruitment of many species. As would be expected, some species are abundant within one zone and not another and catches were typically dominated by a few species. Brook silversides was most abundant in both years in the transitional and lacustrine zones while shad were dominant in the riverine zone both years (Table 4-6 and Figure 4-15).

Table 4-6. Summary of seining data during June and July 1990 and 1991.

Species	Riverine		Transitional		Lacustrine	
	Count	Percent	Count	Percent	Count	Percent
1990						
shad	8198	81.88	464	19.17	0	0.00
brook silverside	401	4.01	614	25.36	1523	68.95
sunfish	391	3.91	83	3.43	90	4.07
central stoneroller	369	3.69	53	2.19	76	3.44
shiner	362	3.62	366	15.12	163	7.38
minnow	163	1.63	55	2.27	35	1.58
largemouth bass	46	0.46	118	4.87	78	3.53
smallmouth buffalo	31	0.31	0	0.00	24	1.09
bluegill sunfish	27	0.27	44	1.82	9	0.41
western mosquitofish	9	0.09	1	0.04	4	0.18
channel catfish	3	0.03	27	1.12	0	0.00
white bass	3	0.03	53	2.19	18	0.81
darter	2	0.02	0	0.00	1	0.05
white crappie	2	0.02	2	0.08	0	0.00
buffalo	1	0.01	0	0.00	0	0.00
gizzard shad	1	0.01	2	0.08	6	0.27
green sunfish	1	0.01	2	0.08	3	0.14
smallmouth bass	1	0.01	1	0.04	3	0.14
walleye	1	0.01	1	0.04	0	0.00
chub	0	0.00	0	0.00	0	0.00
freshwater drum	0	0.00	4	0.17	0	0.00
logperch	0	0.00	2	0.08	1	0.05
longear sunfish	0	0.00	0	0.00	2	0.09
river carpsucker	0	0.00	0	0.00	0	0.00
spotted bass	0	0.00	11	0.45	18	0.81
threadfin shad	0	0.00	518	21.40	155	7.02
1991						
shad	23181	91.19	672	28.19	274	15.58
brook silverside	1235	4.86	1144	47.99	980	55.71
shiner	327	1.29	121	5.08	179	10.18
minnow	324	1.27	198	8.31	86	4.89
central stoneroller	118	0.46	103	4.32	43	2.44
white crappie	90	0.35	0	0.00	0	0.00
gizzard shad	41	0.16	0	0.00	30	1.71
sunfish	38	0.15	25	1.05	83	4.72
western mosquitofish	31	0.12	0	0.00	0	0.00
bluegill sunfish	9	0.04	38	1.59	2	0.11
spotted bass	9	0.04	9	0.38	46	2.62
largemouth bass	5	0.02	19	0.80	9	0.51
river carpsucker	5	0.02	0	0.00	0	0.00
logperch	3	0.01	4	0.17	1	0.06
chub	2	0.01	0	0.00	0	0.00
threadfin shad	2	0.01	28	1.17	14	0.80

Species	Riverine		Transitional		Lacustrine	
	Count	Percent	Count	Percent	Count	Percent
buffalo	0	0.00	0	0.00	0	0.00
channel catfish	0	0.00	10	0.42	0	0.00
darter	0	0.00	0	0.00	0	0.00
freshwater drum	0	0.00	0	0.00	0	0.00
green sunfish	0	0.00	9	0.38	7	0.40
longear sunfish	0	0.00	3	0.13	0	0.00
smallmouth bass	0	0.00	0	0.00	5	0.28
smallmouth buffalo	0	0.00	0	0.00	0	0.00
walleye	0	0.00	0	0.00	0	0.00
white bass	0	0.00	1	0.04	0	0.00

Data from Oklahoma Department of Wildlife Conservation.
Data are sorted in descending order according to species percentage in the riverine section.

While one dataset alone cannot provide an overall assessment of the health of the Lake Tenkiller fishery, an assessment of various datasets including sportfish collections from electroshocking and gillnet sets and forage and recruitment from seining data can assist in understanding fisheries dynamics within the lake. Differences may be expected due to the three zones observed in Lake Tenkiller (Riverine, Transitional, Lacustrine) and species requirements. Assessing these at both the lake wide and zone level have provided insight into the Lake Tenkiller fisheries. This lake is a managed fishery with catch-limits put in place to increase the catch rate or sizes of fish captured by anglers. In addition, lake levels also are fairly strictly managed, which can lead to stress or recruitment failure for some species depending on the timing and extremity of water level fluctuations. Catch rates for bass are among some of the highest in the state with most years qualifying as a high quality bass fishery. Largemouth bass are the most highly sought bass species for anglers, and management strategies have focused on creating a quality largemouth bass fishery, including development of a Largemouth Bass Management Plan by the ODWC (ODWC 2009b). Based on the discussion and analyses above, it apparent that Lake Tenkiller is a desirable fishery. The lake fishery is in no way “damaged,” as reported by the Plaintiffs’ consultants, Drs. Cooke and Welch.

SECTION 6
THE WATER QUALITY IN THE ILLINOIS RIVER WATERSHED IS COMPARABLE TO OTHER WATERS IN OKLAHOMA

6.1 SUMMARY OF DETAILED FINDINGS

- The water quality of Lake Tenkiller is comparable to other systems within Oklahoma.
- Water quality of the rivers, specifically, Illinois River, is comparable to other rivers within Oklahoma.

6.2 THE WATER QUALITY OF LAKE TENKILLER IS COMPARABLE TO OTHER SYSTEMS WITHIN OKLAHOMA

Each year, the OWRB compiles a report detailing the state of water quality within Oklahoma's lakes and rivers (i.e., the BUMP report). In addition, every other year, Oklahoma is required by the USEPA to assess all waters of the state and determine which are not meeting their designated uses (e.g., fishable, swimmable, drinkable, etc.). Those not meeting their uses are called "impaired" and are required to undergo additional monitoring and analysis to determine what needs to be done to eliminate the impairment. These two water quality assessment exercises allow us to compare Lake Tenkiller's water quality to other reservoirs and lakes in the state.

The monitoring program for the BUMP tends to focus on water bodies that have potential water quality concerns and therefore, can result in a somewhat "biased" view of the water quality in the state. However, comparisons can still be made, while keeping this sampling protocol in mind. A review of the 2007 BUMP report provides a comparison of Lake Tenkiller's TSI with other sampled reservoirs and lakes (OWRB 2007). As discussed in Section 2, a TSI provides an estimate of the level of eutrophication in a lake, with higher numbers indicating greater eutrophication, in general. Figure 6-1 shows the chlorophyll-a TSIs for all lakes and reservoirs sampled from 2004 to 2007. These TSIs are representative of the summer (i.e., the BUMP sampling period) and include data from the entire water body (i.e., the BUMP assessment does not break out a reservoir into riverine, transitional, or lacustrine zones). Figure 6-1 indicates that 61% of the lakes sampled from 2004 to 2007 were classified as eutrophic or hypereutrophic, according to its chlorophyll-a TSI. Lake Tenkiller was one of those reservoirs, but 14% of the lakes were at a higher tropic level (hypereutrophic) than Lake Tenkiller. The probability distribution of the chlorophyll-a TSIs calculated from 2004 to 2007 shows that Lake Tenkiller lies at about the 58th percentile, meaning that about 42 percent of the lake's sampled had TSIs higher than Lake Tenkiller (Figure 6-2, bottom panel). In addition, the spatial pattern of chlorophyll-a TSI determined from Plaintiff's data collected in summer 2006 indicates that Lake Tenkiller's lacustrine area (represented by LK-01 and LK-02) is mesotrophic, which is typical for a run-of-the-river reservoir (see Horne 2009 for further discussion).

Inspection of total phosphorus collected during the BUMP effort shows a story similar to chlorophyll-a. Figure 6-3 displays the total phosphorus concentrations of the different reservoirs for summers of 2005 and 2007. Forty-percent of the lakes sampled during these two summers had phosphorus in the same range as Lake Tenkiller, while 37% had concentrations in a range higher than Lake Tenkiller.

Table 6-1 shows the biennial assessment of state waters from the preliminary 2008 report that was submitted to USEPA (ODEQ 2008). Only the constituents for which Lake Tenkiller is listed as "impaired" are shown in the table. Close to 11% of the assessed lakes are considered impaired based on chlorophyll-a and close to 63% of Oklahoma's assessed lakes are listed for low dissolved oxygen. Lake Tenkiller's chlorophyll-a impairment accounts for just 1.4% of the total assessed lakes and about 2% of the all the assessed lakes in relation to dissolved oxygen impairment. More importantly, Table 6-1 shows that there are many other lakes within Oklahoma that have water quality impairments. The assessment for total phosphorus is not yet performed on a state-wide basis and therefore, it is difficult to draw any conclusions regarding the impairment listing of Lake Tenkiller for total phosphorus.

Table 6-1. Percentage of lakes in Oklahoma with similar impairments as Lake Tenkiller.

Impairment	Size of Lake Tenkiller Impaired (acres)	Waterbodies in Illinois River Watershed		Lakes in Oklahoma		
		Total Lake Size Impaired (acres)	Total Lake Acres Assessed within Watershed	Total Acres of Lakes Impaired in Oklahoma (acres)	Total Lake Acres Assessed, with Sufficient Data or Information [2]	% of Assessed Lake Acres Impaired
Chlorophyll-*a*	8,440	8,440	14,034	66,222	622,176	10.6%
Dissolved Oxygen	13,470	13,470	14,034	389,498	622,176	62.6%
Total Phosphorus	8,440	8,440	n/a [3]	15,877	n/a [3]	---

Notes:

1. *Source: Oklahoma Department of Environmental Quality, 2008. The State of Oklahoma 2008 Water Quality Assessment Integrated Report.*
2. *Excludes 303(d) List Category 3 stream miles. Integrated report does not list acres assessed by impairment, only total acres assessed for any one constituent..*
   Category 3 - Insufficient or no data and information to determine if any designated use is attained.
3. *n/a = not available; lakes assessed for phosphorus unknown.*

The above information, combined with the analysis performed in Section 2.8 (i.e., the analysis of water quality in Lakes Hugo and Sardis watersheds) indicates that Lake Tenkiller's water quality is comparable to other reservoirs within the state. The water quality of Lake Tenkiller is not unusual and does not indicate significant issues. In fact, for a large portion of the lake (the lacustrine zone), the water quality is well within acceptable levels for chlorophyll-a and total phosphorus.

6.3 THE WATER QUALITY OF THE ILLINOIS RIVER IS COMPARABLE TO OTHER SYSTEMS WITHIN OKLAHOMA

6.3.1 Dissolved Oxygen Levels in the Illinois River Watershed Are Comparable or Better Than Many Other River Systems within Oklahoma

According to the State of Oklahoma's 303(d) list, low dissolved oxygen is a common problem in the state. About 2,500 miles of rivers and streams are listed as impaired for dissolved oxygen (Table 6-2). This represents about 20 percent of the total river miles assessed by the state. Within the Illinois River Watershed, the state listed only 1.6 miles as impaired due to dissolved oxygen and no part of the main stem of the Illinois River.

Table 6-2. Percentage of rivers/streams/creeks in Oklahoma with similar impairments as those in the Illinois River and its watershed.

Impairment [2]	Main Stem of Illinois River	All Waterbodies in Illinois River Watershed			Rivers/Streams/Creeks in Oklahoma		
	Total Stream Miles Impaired	Total Stream Miles Impaired	Total River Miles Assessed [3]	% of Assessed Stream Miles Impaired	Total Stream Miles Impaired	Total River Miles Assessed, with Sufficient Data or Information [4]	% of Assessed Stream Miles Impaired
Dissolved Oxygen	0	1.6	551.5	0.3%	2,547	12,511	20.4%
Enterococcus	12.9	112.2	551.5	20.3%	6,977	12,511	55.8%
Escherichia Coli	31.7	37.9	551.5	6.9%	3,495	12,511	27.9%
Fecal Coliform	31.7	31.7	551.5	5.7%	3,094	12,511	24.7%
Lead	31.7	31.7	551.5	5.7%	1,437	12,511	11.5%
Total Phosphorus	60.2	92.8	92.8	100.0%	160	185 [5]	86.5%
Turbidity	5.2	5.2	551.5	0.9%	4,012	12,511	32.1%

Notes:
1. *Source: Oklahoma Department of Environmental Quality, 2008. The State of Oklahoma 2008 Water Quality Assessment Integrated Report.*
2. *Only impairments listed for the main stem of the Illinois River are listed.*
3. *Appendix B of integrated report does not list miles by impairment. Assumed that miles reported pertain to all constituents except phosphorus.*
4. *Excludes Category 3 stream miles. Integrated report does not list miles assessed by impairment, only total miles assessed.*
   Category 3 - Insufficient or no data and information to determine if any designated use is attained.
5. *Total river miles estimated from 'Scenic River'-designated water bodies in Oklahoma.*
   Estimated based on Scenic River area descriptions in Oklahoma Statute.
   Length of Big Lee's Creek not limited by the 420-foot MSL elevation due to limited available information.

Using data collected between 2004 and 2007, I looked at dissolved oxygen conditions throughout the state.[26] Many locations failed to meet the dissolved oxygen standards[27] and a number of locations had problems in multiple years (Figure 6-4). In contrast, within the Illinois River Watershed only one small section of river did not meet standards, and that was only during one of the four years considered.

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[26] Only locations with at least eight records in at least two years were considered. In addition, to ensure year-round oxygen status, only locations with at least one dissolved oxygen records in at least three quarters (three-month periods) were considered.

[27] The Oklahoma dissolved oxygen regulations are written such that if 10% of readings at a particular location are found to be below a certain criteria, that location is considered impaired due to low dissolved oxygen. In the summer in the much of the Illinois River Watershed, that the criteria are 5.0 mg/L., and 6.0 mg/L for the rest of the year. In some other areas of the Oklahoma the summer and rest-of-the-year the criteria are 4.0 mg/L and 5.0 mg/L, respectively.

This four-year assessment, combined with lack of Illinois River Watershed waters on the state 303(d) list, demonstrates that dissolved oxygen is not a particular concern in the Illinois River Watershed.

6.3.2 Bacteria Indicator Levels in the Illinois River Watershed Are Comparable to Other Systems within Oklahoma

Bacteria groups that may be monitored as indicators of risk for water-transmitted illness from fecal contamination to humans are reviewed in Section 5.2 of this report. River locations throughout the state of Oklahoma are routinely tested for all three standard indicator bacteria groups. Here, results throughout Oklahoma were compared to determine the relative degree of indicator bacteria contamination within the Illinois River Watershed to statewide levels of contamination.

6.3.2.1 Data sources and analysis methods for Oklahoma bacterial indicator comparison

Oklahoma indicator bacteria data were compiled from the following databases: the USGS, the OWRB, the Oklahoma Conservation Commission, USEPA STORET, and the Oklahoma Attorney General. Only data results in units of CFU/100 ml or MPN/100 ml were considered, and values below the detection limit were set equal to the detection limit for analysis. Sample IDs for each USGS/Oklahoma sampling location were standardized so that all available data could be combined for each location (OK station ID formats varied among data sources and the USGS and OK use different ID series for the same stations).

According to USEPA guidance, to indicate the typical impairment level of a water body, one uses the geometric mean of bacteria counts in samples collected over the duration of the swimming season (USEPA 1986, 2004). This is the period during which full-body immersion resulting in oral disease transmission is most likely to occur. Therefore, in this analysis, only samples collected from May through September, the likely extent of the swimming season in Oklahoma and the usual sampling period for the USGS and Oklahoma, were included. Samples in each swimming season were combined to calculate the seasonal geometric mean for that year and location. Duplicates and other cases of multiple samples per day were averaged to get one value per date prior to geometric mean analysis.

The geometric means calculated here are not directly comparable to water quality standards because a lower cutoff for frequency of sampling was used. The point of this analysis is to compare statewide results to each other, not to a standard. (USEPA guidance indicates bacteria samples should be collected at a frequency of five per 30 days for public swimming locations, but the Oklahoma data were typically collected less frequently, usually 1-2 times per month). Geometric means were calculated only in cases where there were at least five sampling dates per season for that location (a frequency of at least one per month).

Results were analyzed for the 2003, 2004, and 2006 swimming seasons. There was insufficient sampling in 2005, 2007, and 2008 to conduct statewide comparisons for those years. Earlier years were not considered.

6.3.2.2 Results of Oklahoma bacterial indicator comparison

Enterococci geometric means for May through September throughout Oklahoma are shown for 2003, 2004, and 2006 in Figures 6-5a, 6-5b, and 6-5c respectively. The Illinois River Watershed is shaded grey in all figures, and results are color coded with respect to how the geometric mean compares to the USEPA water quality criteria threshold (WQT) of 33/100 ml (CFU/100 ml or MPN/100 ml) for enterococci. In 2003, no site in Oklahoma had a seasonal value for enterococci below the WQT, and values in excess of 5 times (5x) the WQT occurred frequently throughout the state. However, the Illinois River Watershed contained a lower concentration of enterococci (some values in the 1-2x WQT range) than was typical for the state. In 2004, enterococci values were somewhat lower than 2003, but the majority of sampled locations both within and outside of the Illinois River Watershed were still in excess of 2x the WQT. In 2006, while there were far more enterococci results < 2x the WQT, some values > 5x the WQT still occurred, however values did not exceed 5x the WQT in the Illinois River Watershed, and did not exceed 1x the WQT in Lake Tenkiller.

Escherichia coli geometric means for May through September in Oklahoma are shown for 2003, 2004, and 2006 in Figures 6-5d, 6-5e, and 6-5f respectively. Results are color coded with respect to the 126/100ml WQT for *E. coli*. In contrast to enterococci, *E. coli* values > 1x the WQT were relatively rare in all three years. More values > 1x the WQT occurred in 2003 and 2006, than in 2004, including two within the Illinois River Watershed in 2003. There were no *E. coli* geometric mean values > 1x the WQT in the Illinois River Watershed in 2004 or 2006.

Fecal coliform geometric means for May through September in Oklahoma are shown for 2003, 2004, and 2006 in Figures 6-5g, 6-5h, and 6-5i respectively, with results color coded with respect to the 200/100ml WQT for fecal coliform. In keeping with enterococci and *E. coli* results, geometric mean values for fecal coliform within the Illinois River Watershed were similar to, or less than, the rest of Oklahoma.

In summary, this data analysis found the magnitude of seasonal indicator bacteria geometric mean values in the Illinois River Watershed were typical of values throughout the entire state of Oklahoma. Thus, there is no evidence that local poultry litter application contributes to exceptional levels of indicator bacteria, and by association risk of waterborne illness, within the Illinois River Watershed.